AN OUTDOOR TESTING FACILITY FOR FLAT PLATE COLLECTORS

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Discussion Paper No : 03/88

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FEBRUARY 1988

CONTENTS

LIST OF FIGURES

ABSTRACT

The test set-up for flat plate collectors has been described in detail and the method specified. The experimental facility has been established and perfected at TERI, New Delhi over a span of two years and the commercial collector has been successfully tested. The tests yielded consistent and repeatable results.

KEYWORDS

Flat Plate Collector; Collector Testing.

INTRODUCTION

Many private companies manufacturing solar hot water systems have come into existence, ever since the Department of Non-Conventional Energy Sources (DNES) started giving attractive incentives to solar energy devices. It has, therefore, become necessary to test and rate different collector systems on a standardized rational basis. Keeping this in view, a test facility has been developed by Tata Energy Research Institute (TERI), New Delhi, for testing and evaluating flat plate collectors. The test method is based on a combination of the methods of the Commonwealth Scientific Industrial Research Organization (CSIRO) [1] and the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) [2], and is described in the following section.

DESCRIPTION OF THE TEST SET-UP

A schematic diagram of the test set-up is shown in Figure 1. The salient features of the test loop are :

(i) a combination of open loop and closed loop characteristics;

(ii) constant head gravity flow for maintaining a constant flow rate through the loop;

(iii) tracking provided for the enhancement of testing time;

(iv) a radiation shield provided for high temperature runs;

(v) large thermal mass of water to minimize fluctuations in the inlet temperature; and

(vi) a simple, area-adjustable cooling device for heat removal from the collector outlet stream.

The collector test facility consists of : (i) a rotatable stand to hold one collector to be tested; (ii) a main water supply tank and header tank to facilitate constant water flow rate through the collector; (iii) instrumentation to measure the incident solar radiation, water inlet and outlet temperatures, as well as ambient temperature; (iv) mass flow rate of water; and (v) a simple heat exchanger (an open tray).

The collector stand faces south in a normal operation. The collector can be rotated from East to West to ensure almost constant insolation for periods of three to four hours. The horizontal tilt can also be varied to allow for near-normal incidence in different seasons. The main supply tank and header tank are thermally insulated to keep the water inlet temperature stable. A constant flow rate through the collector is achieved by maintaining a constant head in the header tank with overflow back to the main supply tank. During a test, the collector outlet water is run onto an open tray. Water from the cooling tray goes back to the main tank by gravity flow. The flow rate through the collector can be controlled by adjusting the vertical height of the discharge point on the collector hose. An air-vent valve (Figure 8) is located at the collector outlet to eliminate air pockets in the collector.

The following sections describe the component parts of the set-up in more detail.

Collector Stand

The collector stand consists of two main frames which have an open construction of angle iron with overall dimensions of 2145 mm x 1145 mm (outer frame) and 2025 mm x 1025 mm (inner frame). It is mounted on a shaft (Figure 2), which can be rotated horizontally through 180°. The inclination of the stand can be adjusted upto 75° (approximately). The collector is mounted on the inner frame which can be rotated about the North-South (longer dimension) axis, for any given position of the outer frame. This arrangement (Figure 3) allows the collector to be tilted away from near-normal incidence of radiation so that the variation of $(\tau\alpha)$ with incidence angle can be studied for a given cover system.

Supply Tank

The main supply tank (Figure 4) has a capacity of 100 litres. The inner tank is made of an 18-gauge G.I. sheet and the outer casing of a 22-gauge G.I. sheet. The supply tank is lagged with a 10 cm thick glass wool insulation. A 2 kW electric heater is fixed at the bottom of the main supply tank to heat the water to any desired temperature and a lid is provided to gain access to the tank. A variac (Figure 10) is used to compensate for the heat losses from the main supply tank, overhead tank, etc., in order to maintain a constant temperature during the test period.

Header Tank

The header tank (Figure 5) has a capacity of 30 litres. It is made of a 20-gauge G.I. sheet; the outer casing is made of a 22-gauge G.I. sheet. Insulated with 10 cm thick glass wool all around, the tank is positioned about 2 M. directly above the supply tank and supported by a galvanized iron pipe frame. Water from the supply tank is pumped by a Tullu-50 (Figure 4) into the header tank in which a constant head is maintained during the tests by an overflow return to the supply tank. All connections between the supply and header tank are made of insulated G.I. pipes.

Heat Exchanger (Open Tray)

This is positioned at the outlet of the collector and is slightly inclined towards the main supply tank. The water from the outlet of the collector passes onto the open tray and back to the main supply tank (see Figures 6 and 7). The function of the open tray is to reject the excess heat gained by water (while passing through the collector) to the atmosphere, mainly by evaporation. By adjusting the point of entry on to the tray, the area of heat losses can be adjusted and hence the total amount of heat dissipation can be regulated.

INSTRUMENTATION

Temperature Measuring Sensors

A Vaiseshika 20-channel digital thermometer with a precision of 0.1^{o}C is used to measure the water inlet, outlet and ambient temperatures (Figure 10). The temperature sensors (probes) to measure the collector water inlet and outlet temperatures are permanently located in T-joints (couplings) which can be connected and dismantled at will (Figure 8). This allows collectors to be interchanged readily

without the need to fit temperature sensors (probes) each time. The T-joints (couplings) are well-insulated and the probes are positioned so as to ensure that the direction of water flow is parallel to the vertical length of the probe.

A small piece of twisted metallic wire mesh is inserted in the water-flow path a few centimetres before the probe so that the stream is well mixed. The ambient temperature probe is housed in a properly vented and shielded box (Stevenson box, Figure 7).

Pyranometer

A precision pyranometer supplied by Rainmeters, Bangalore, is used to measure the incident solar radiation. The pyranometer (Figure 9) is fixed in the same plane as the collector to a separate plate which in turn is fastened onto the stand. A Vaiseshika digital potentiometer (10-channel digital thermocouple test-set) with a precision of 0.01 mV is used to record the output from the pyranometer in millivolts, giving a precision of about 1.00 Wm^{-2} in the radiation measurement (Figure 10).

Mass Flow Rate

The mass flow rate of water is measured by collecting water in a graduated jar with a measuring accuracy of 10 cc (0.01 kg) for a given interval of time (Figure 7).

Sun Tracker

A simple but accurate device, this has been used to position the collector for near-normal incidence. A narrow metallic rod with a fine tip at the top is fixed beside the collector surface (Figure 9). Under conditions of near-normal incidence, the shadow of the rod is

parallel to the longer (North-South) dimension of the collector.

Radiation Shielding

To evaluate the efficiency of the collector at high values of $(T_{fm} - T_a)/G$, it is necessary to have a radiation shield so that the effective radiation incident on the collector plane can be reduced. To achieve this, a white mosquito net is fixed 30 cm above and parallel to the plane of the collector by means of a metallic frame (Figure 8). The white mosquito net shown in Figure 11, also covers the pyranometer.

COLLECTOR THERMAL PERFORMANCE CHARACTERISTICS

The instantaneous efficiency of the collector under steady or quasi-steady state conditions [3] can be expressed as :

$$\eta = F' \left[(\tau\alpha)_0 - \frac{U_L(T_{fm} - T_a)}{G} \right] \quad \ldots\ldots\ldots\ldots\ldots(1)$$

Where, η = instantaneous efficiency of the collector

F' = collector efficiency factor

$(\tau\alpha)_0$ = transmittance-absorptance product

U_L = overall heat loss coefficient of the collector, $Wm^{-2}{}^{o}C^{-1}$

T_{fm} = mean fluid temperature in the collector, ^{o}C

T_a = ambient temperature, ^{o}C

G = total solar radiation on the plane of the collector, Wm^{-2}

The instantaneous efficiency of the collector can be calculated from experimental measurements of mass flow rate of water, incident solar radiation and water inlet and outlet temperatures, using the following equation :

$$\eta = \frac{\int \dot{m} C_p (T_o - T_i) dt}{\int G A_c dt} \qquad \text{............(2)}$$

Where, $\dot{m}$ = mass flow rate of water through the collector, kgs^{-1}

C_p = specific heat of water, $Jkg^{-1} {}^oC^{-1}$

T_o = water outlet temperature, ^oC

T_i = water inlet temperature, ^oC

A_c = absorber area of the collector, m^2.

Equation (1) indicates that if the efficiency is plotted against $(T_{fm} - T_a)/G$, a straight line will result. The slope of the straight line will be equal to $F'U_L$ and the intercept on the η-axis will be equal to $F'(\tau\alpha)_o$. In reality, U_L is not a constant but rather a function of the temperature of the absorber plate and the ambient weather conditions. Hence, the experimentally obtained value of $F'U_L$ is a mean value.

EXPERIMENTAL PROCEDURE

All experiments were conducted under clear sky conditions. The testing period was usually selected to be about 2 hours, equally spaced around solar noon.

Test Sequence

(a) The water in the main supply tank is heated to the desired temperature.

(b) The surfaces of the collector and pyranometer bulb are cleaned thoroughly. The pump is switched on and water is allowed to flow through the collector. The air-vent valve is opened to ensure that the air pockets are removed from the collector and then closed.

(c) Under steady or quasi-steady state conditions, all the parameters are measured at intervals of 10 minutes. These are:

(i) water inlet temperature

(ii) water outlet temperature

(iii) ambient temperature

(iv) solar radiation, and

(v) mass flow rate

(d) The experiment is repeated on different days for different inlet temperatures.

Test Results

To determine the collector parameters from the data points, the values of efficiency and $(T_{fm} - T_a)/G$ are calculated as indicated below :

(i) The temperature difference between oulet and inlet of the collector is obtained at every 10 minute intervals.

(ii) The mean temperature of water (T_{fm}) in the collector is calculated by taking the average of inlet and outlet temperatures every 10 minutes.

(iii) The useful heat gain (Q_u) is estimated from the product of mass flow rate, specific heat and the temperature rise across the collector for each 10-minute interval.

(iv) The integrated values of heat gain, solar radiation and $(T_{fm} - T_a)/G$ are calculated for a 30-minute interval by applying the trapezoidal rule.

(v) The efficiency of the collector is calculated for a 30-minute interval, using equation (2).

(vi) The instantaneous efficiency is plotted against $(T_{fm} - T_a)/G$ for the test periods.

(vii) A linear least squares fit to the data points is then made. The least squares fit yields the values of $F'(\tau\alpha)_o$, $F'U_L$ and also the correlation coefficients.

The collector parameters evaluated by the present procedure are based on the absorber area of the collector.

Reporting Format

A standard reporting format has been adopted by TERI, which consists of a data sheet, test result format and a graph.

Details of the flat plate collector such as type, name of the manufacturing firm, etc. are entered in the data sheet; a summary of the test details is presented in the result format and a linear least squares fit equation to the experimentally obtained values of efficiency is graphically illustrated.

Figure 12 shows the experimental efficiency as a function of $(T_{fm} - T_a)/G$, together with the least squares fit for a commercial collector.

The standard data sheet and test result format are shown in Appendices B & C, respectively.

REFERENCES

1. Pott, P. and Cooper, P.I., An Experimental Facility to Test Flat Plate Solar Collectors Outdoors, Highett, Victoria, Australia, CSIRO Division of Mechanical Engineering, 1976.

2. ASHRAE, "Methods of Testing to Determine Thermal Performance of Solar Collectors," ASHRAE Standard, 1977, 93-77.

3. Duffie, J.A. and Beckman, W.A., Solar Engineering Thermal Processes, New York, John Wiley and Sons, 1974.

APPENDIX A

Nomenclature

A_c	collector area,	(m^2)
C_p	specific heat of fluid in the collector,	($Jkg^{-1}{}^oC^{-1}$)
F'	collector efficiency factor	(dimensionless)
G	total global solar radiation on the plane of the collector,	(Wm^{-2})
$\dot{m}$	mass flow rate,	(kgs^{-1})
Q_u	useful heat gain,	(W)
t	time,	(sec)
T_a	ambient temperature (DBT of air),	(^oC)
T_{fm}	mean fluid temperature,	(^oC)
T_i	inlet temperature,	(^oC)
T_o	outlet temperature,	(^oC)
U_L	overall heat loss coefficient of the collector,	($Wm^{-2}{}^oC^{-1}$)
η	instantaneous efficiency of the collector	(dimensionless)
η_o	optical efficiency of the collector at near-normal incidence	(dimensionless)
$(\tau\alpha)_o$	transmittance-absorptance product at near-normal incidence	(dimensionless)

APPENDIX B

TATA ENERGY RESEARCH INSTITUTE
Flat Plate Collector Test Report

1. Collector Manufacturer :
2. Test Period : From December 31, 1986 to April 19, 1987.
3. Test Location : New Delhi
   Latitude 28° 35'N
   Longitude 77° 12'E

Collector Description

1. External Dimensions	:	1860 mm x 1240 mm x 155 mm
2. Cover Aperture Area	:	2.3 m^2
3. Absorber Area	:	2.1 m^2
4. Ratio of the Aperture Area to the Absorber Area	:	1.095
5. Number of Covers	:	One
6. Cover Material	:	Glass
7. Bottom Insulation	:	Fibre Glass (Crown-300; Crown-150)
8. Side Insulation	:	Fibre Glass (Crown-300; Crown-150)
9. Case Material	:	Aluminium

Test Conditions

1. Solar Radiation Range (with radiation shield)	:	451 to 596 Wm^{-2}
2. Solar Radiation Range (without radiation shield)	:	722 to 1035 Wm^{-2}
3. Ambient Temperature Range	:	16.6 to 39.4 °C
4. Range of Fluid Inlet Temperature	:	18.5 to 82.8 °C
5. Range of Fluid Flow Rate	:	0.024 to 0.026 kgs^{-1}

Collector Efficiency Expression

$$\eta = \eta_o - U\,(T_{fm} - T_a)/G$$

where, η = instantaneous efficiency of the collector

η_o = efficiency of the collector when $T_{fm} = T_a$ (also called optical efficiency at near-normal incidence)

U = $F'U_L$

F' = collector efficiency factor

$(\tau\alpha)_o$ = transmittance-absorptance product at near-normal incidence

U_L = overall heat loss coefficient of the collector, $Wm^{-2}\,{}^oC^{-1}$

T_{fm} = mean fluid temperature in the collector, (^oC)

T_a = ambient temperature (DBT of air), (^oC)

G = solar radiation intensity on the plane of the collector, Wm^{-2}.

Values derived from the test :

$$\eta = 0.562 - 6.96\,(T_{fm} - T_a)/G$$

Correlation coefficient (r) = 0.995

Efficiency vs $(T_{fm} - T_a)/G$ Curve

See attached graph with linear squares fit of 83 data points.

Note : Calculations are Based on Absorber Area

General Comments :

APPENDIX C

Flat Plate Collector Test Result Format

$$\eta = \text{Efficiency of the collector} = \frac{\int \dot{m} C_p (T_o - T_i)\,dt}{\int G A_c\,dt}$$

C_p = Specific heat of water = 4180 $J kg^{-1} {}^{o}C^{-1}$

A_c = Absorber Area of the Collector

STANDARD TIME t	INLET TEMP. T_i	OUTLET TEMP. T_o	AMBIENT TEMP. T_a	SOLAR RAD. G	MASS FLOW RATE $\dot{m}$	TEMP. DIFF. $T_o - T_i$	AVERAGE TEMP. T_{fm}	HEAT GAIN Q_u	EFFICIENCY η	$\frac{T_{fm} - }{G}$
(HRS)	(^{o}C)	(^{o}C)	(^{o}C)	(Wm^{-2})	(kgs^{-1})	(^{o}C)	(^{o}C)	(W)	(–)	($^{o}Cm^{2}W$

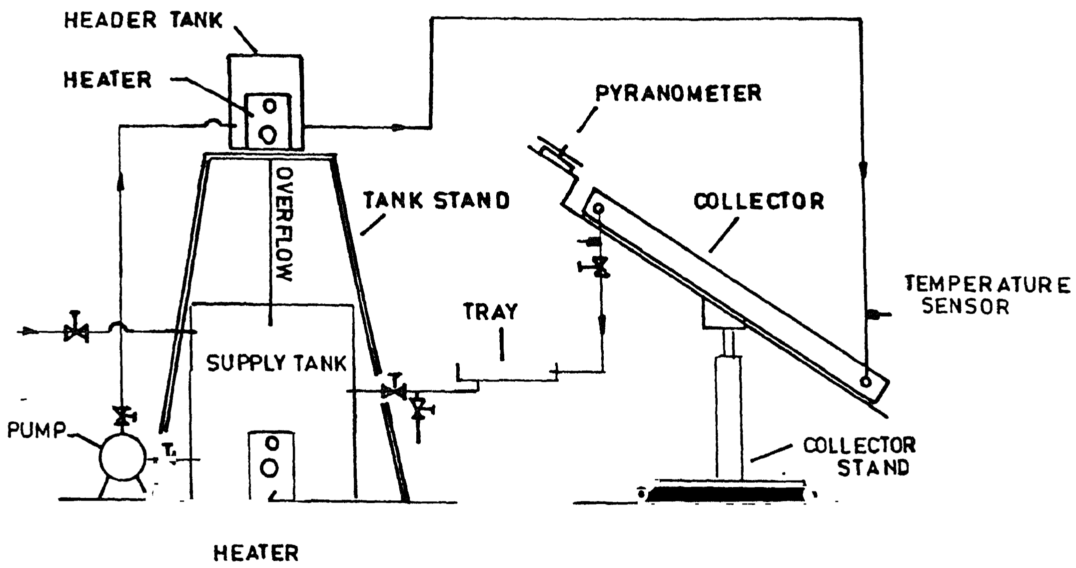


FIGURE 1: Schematic diagram of TERI collector test set-up.

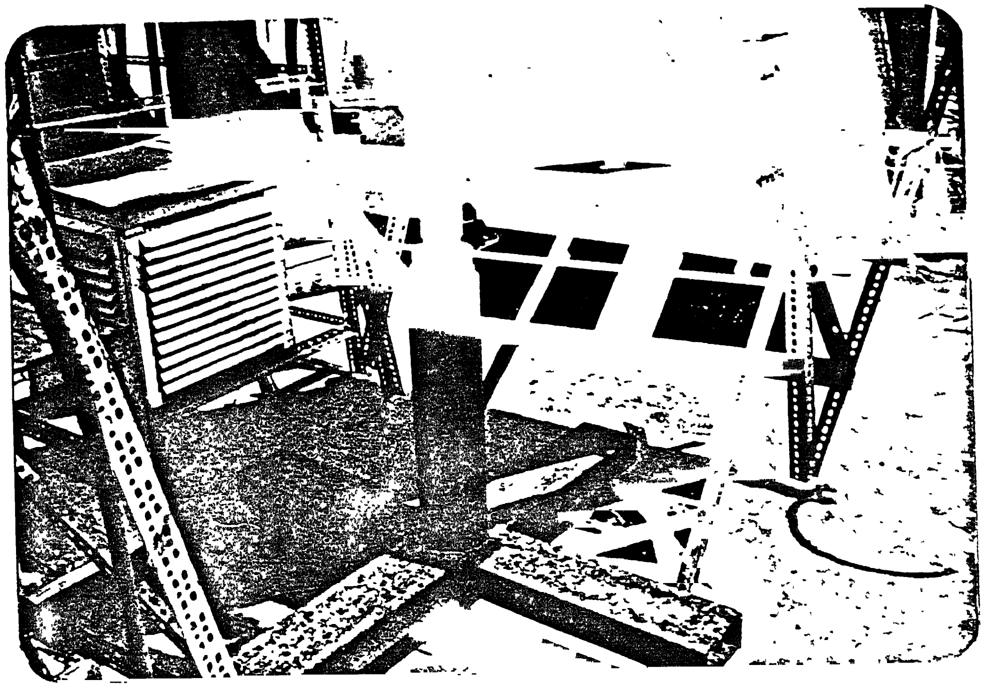
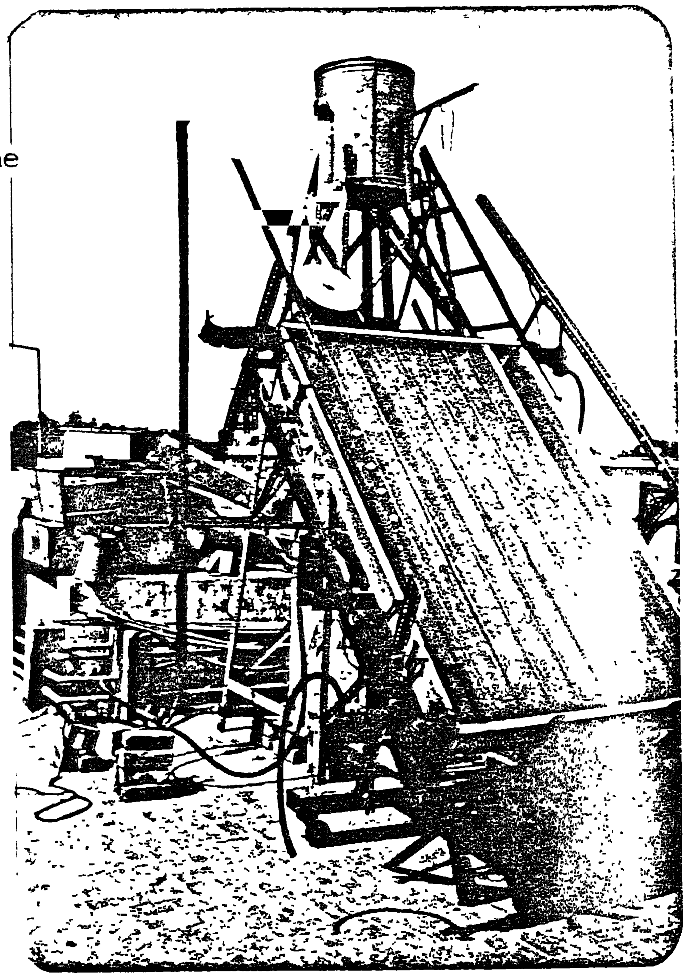


FIGURE 2: Collector test rig frame mounted on a shaft.

FIGURE 3: Collector on the stand.



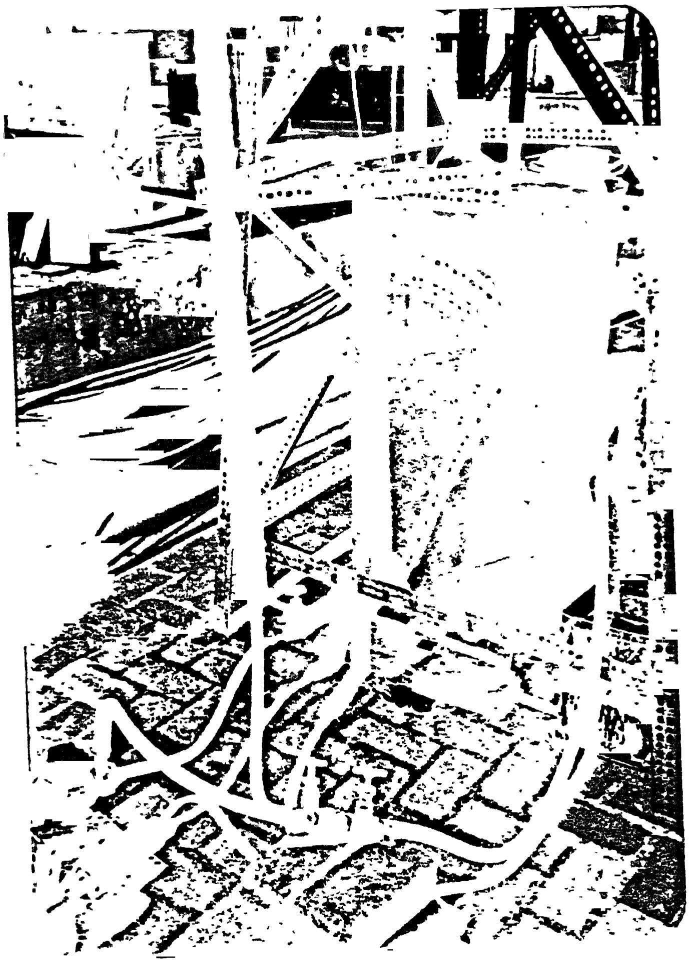
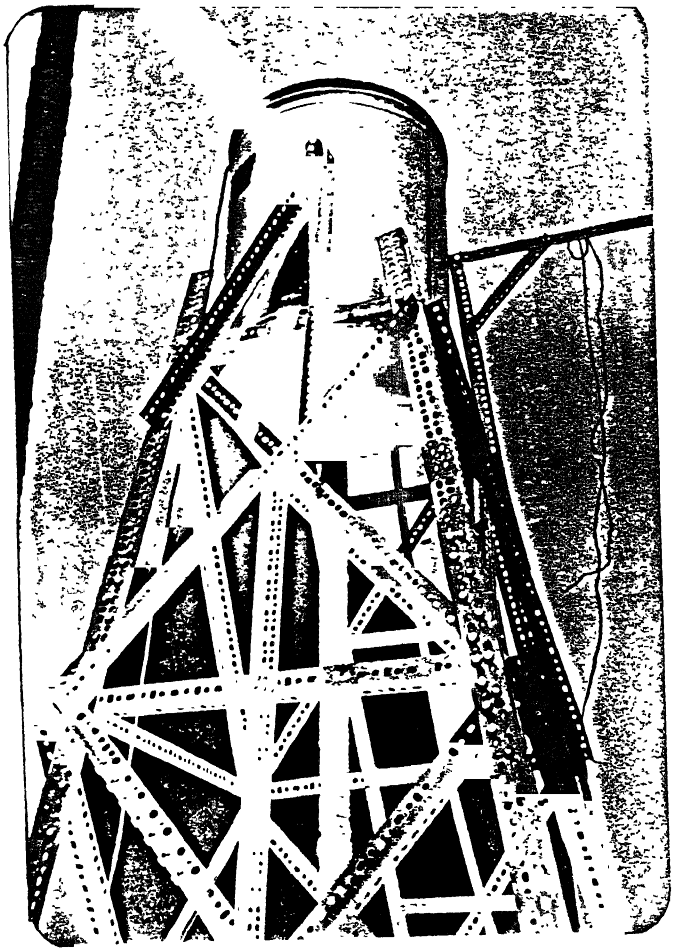


FIGURE 4: Main supply tank connected to Header tank through pump.

FIGURE 5: Header tank on the tower.



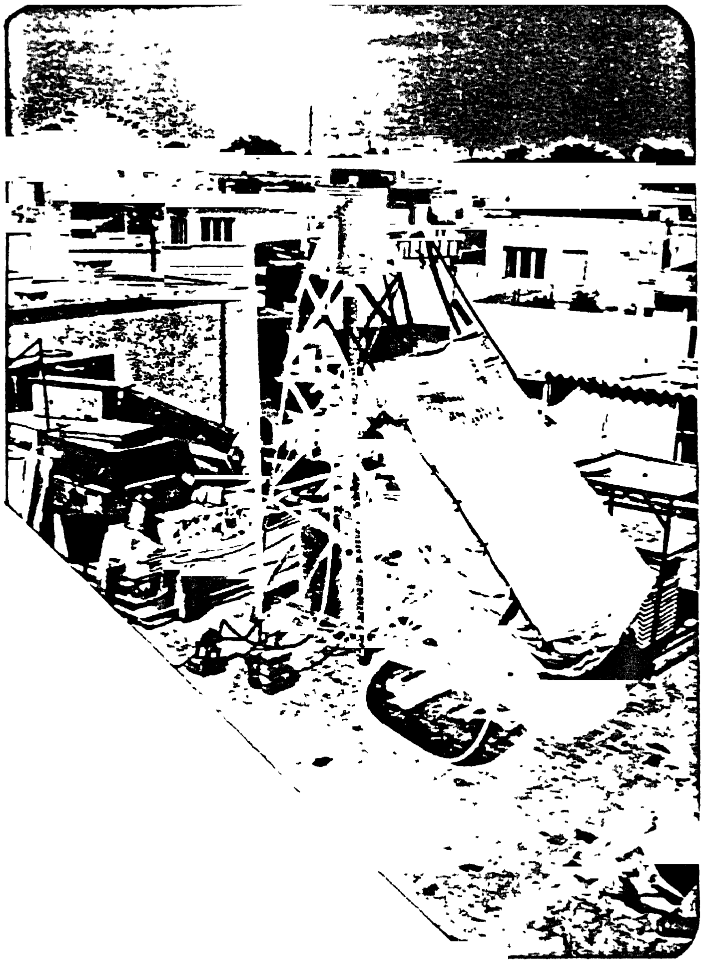


FIGURE 6: Area-adjustable cooling device (an open tray); water from the collector onto the tray.

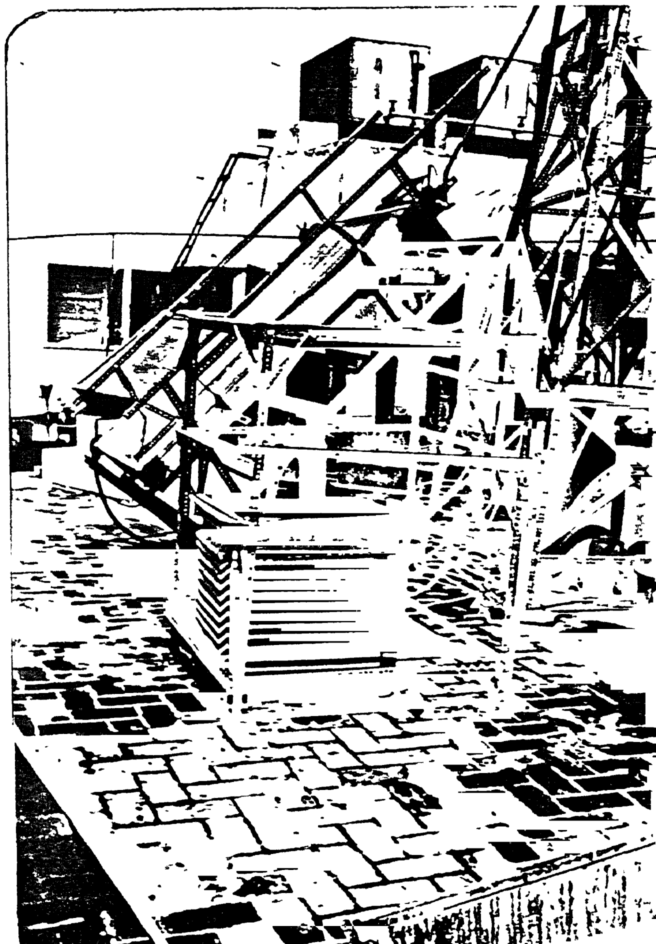


FIGURE 7: (a) Water from the open tray to the main supply tank; (b) Stevenson box; (c) Graduated jar and stop-clock used for the measurement of mass flow rate of water.

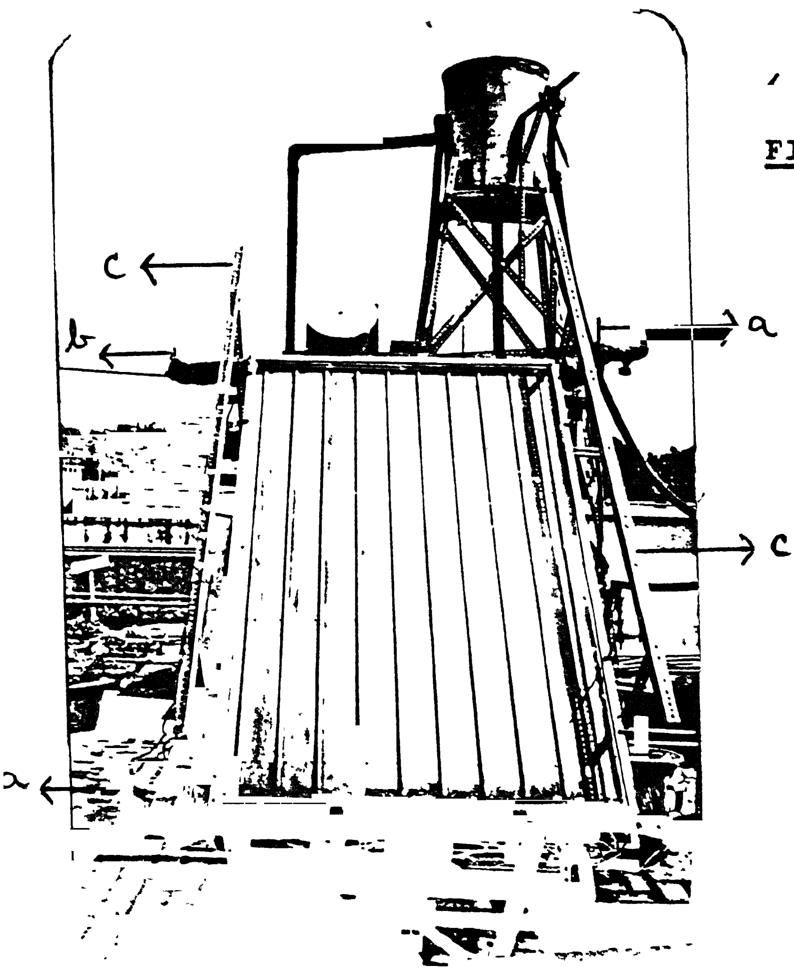


FIGURE 8: (a) Temperature measuring sensors; (b) an air-vent valve; (c) metallic frame for the net used for radiation shielding.

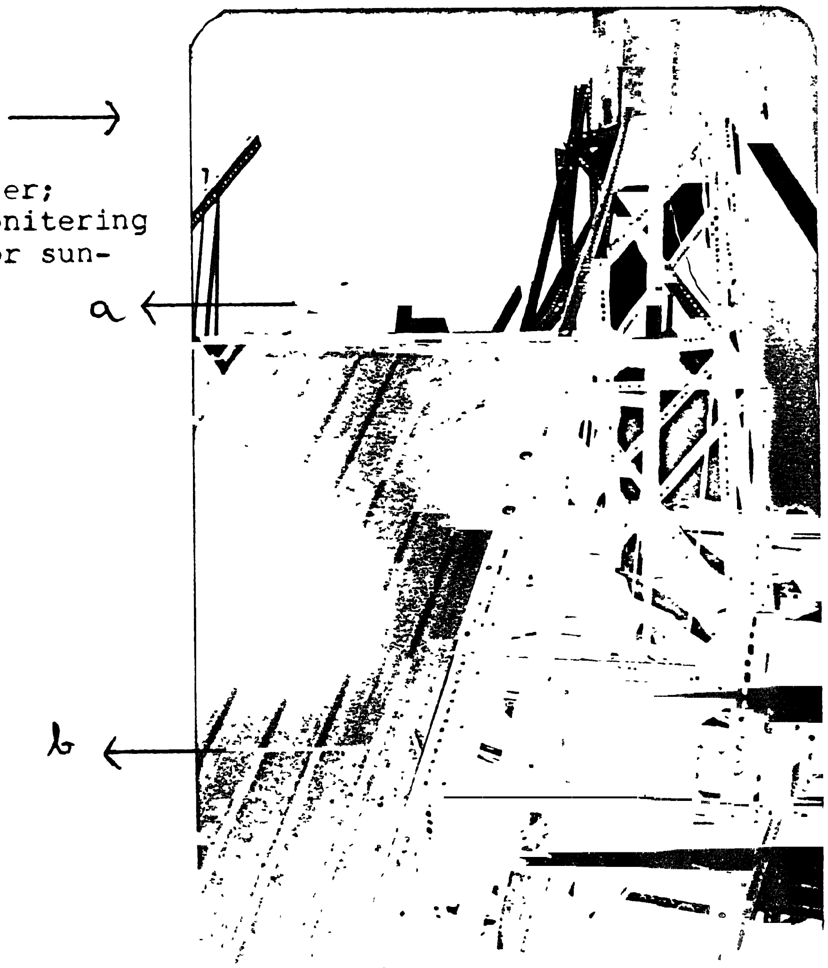


FIGURE 9: (a) Pyranometer; (b) Shadow monitering instrument for suntracking.

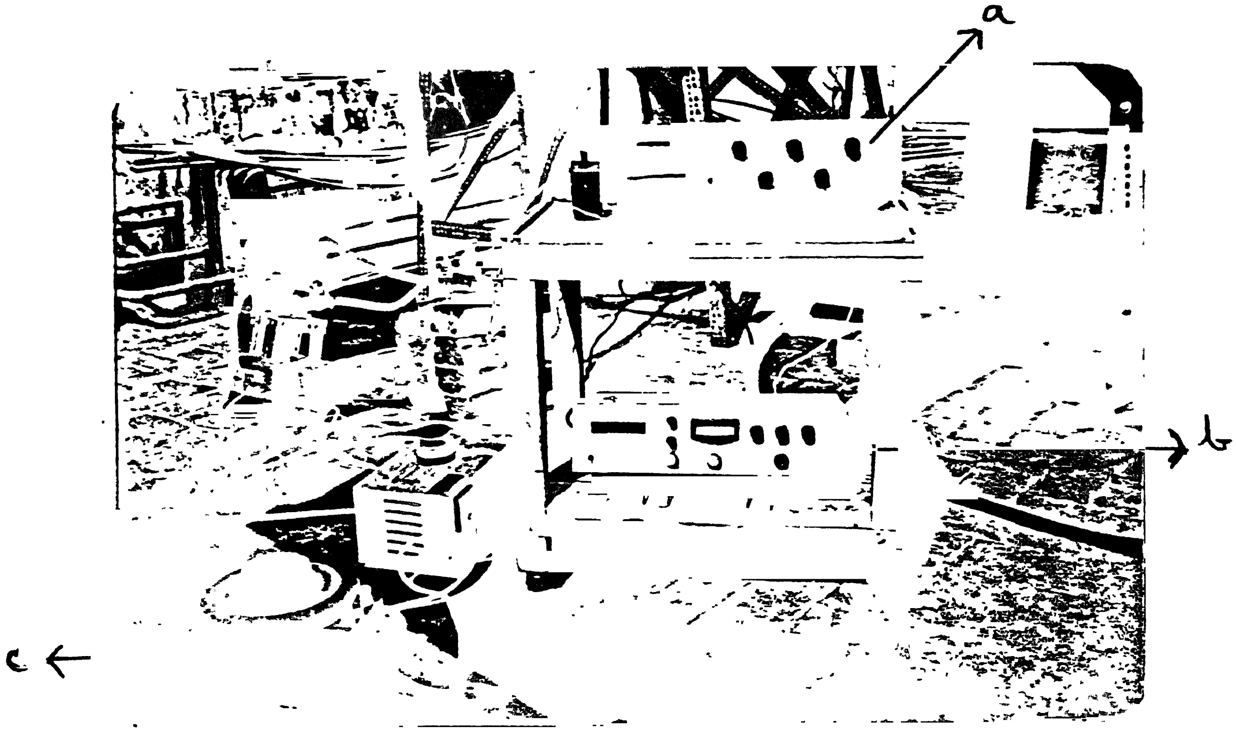


FIGURE 10: (a) Digital thermometer (top); (b) Digital potentiometer (middle); (c) Variac (bottom).

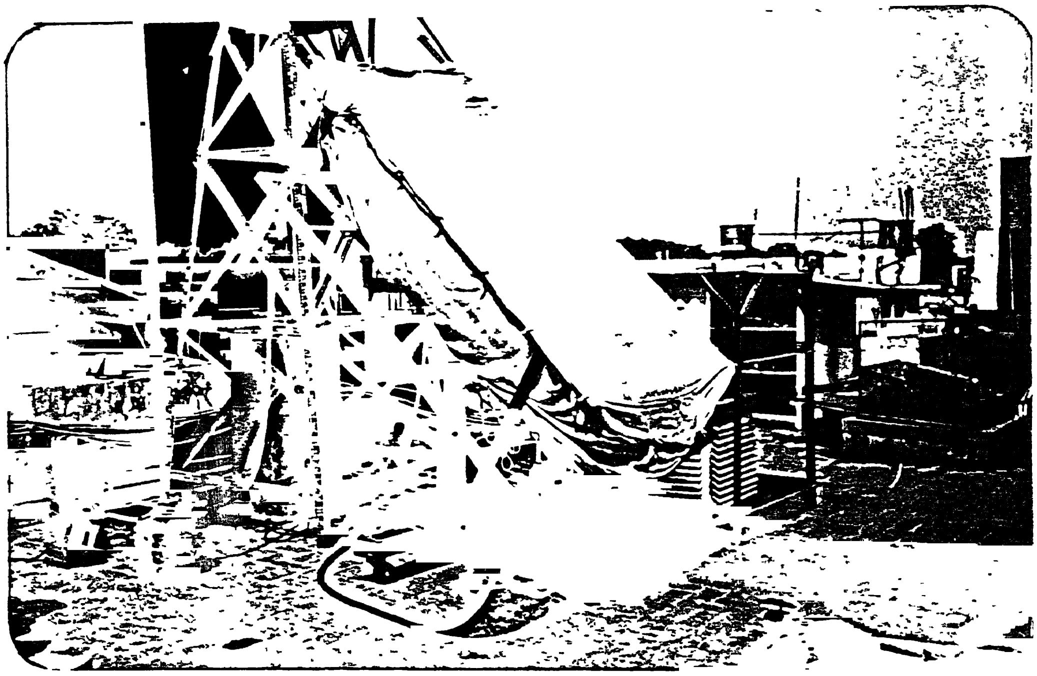


FIGURE 11: White mosquito net mounted on the collector for radiation shielding.

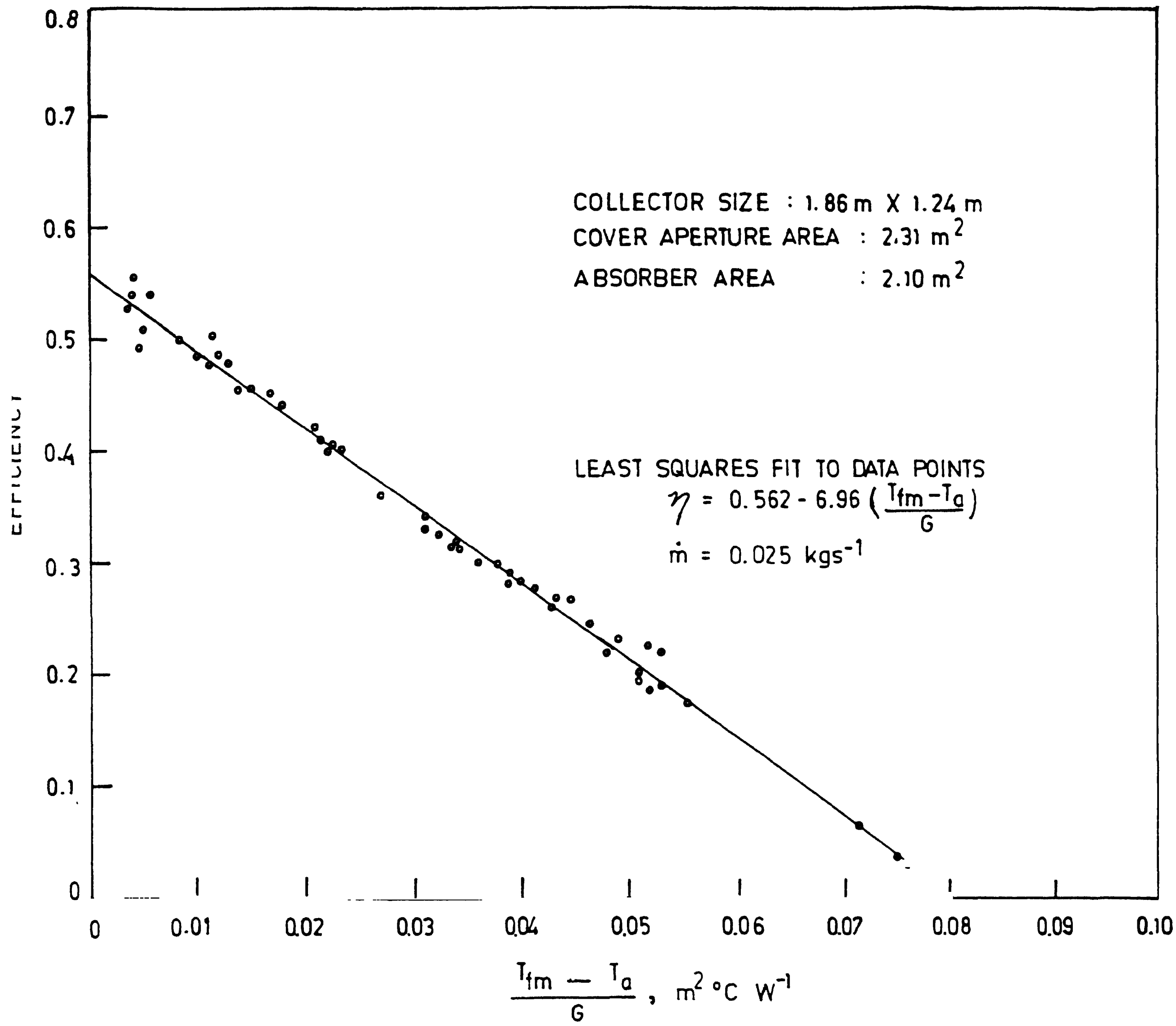


FIGURE 12: Collector Performance.